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ECONOMIC ANALYSIS OF INTEGRATED DOD VOICE AND DATA
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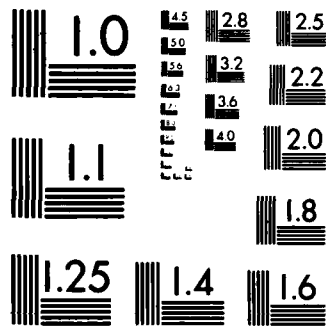
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TECHNICAL ANALYSIS OF
INTERLATCHED VOICE AND DATA NETWORKS
EXECUTIVE SUMMARY

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network analysis corporation

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FINAL REPORT

October 1977

For the Project
**ECONOMIC ANALYSIS OF
INTEGRATED DOD VOICE AND DATA NETWORKS**

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ECONOMIC ANALYSIS OF INTEGRATED DOD VOICE AND DATA NETWORKS

EXECUTIVE SUMMARY

I. OBJECTIVE AND MAJOR CONCLUSION

The objective of this study is to investigate alternative switching strategies for future integrated DOD voice and data networks. Three fundamental problems are addressed:

- The economics of integrating voice and data applications in a common communications ^{network} system.
- The comparison of alternative switching technologies for integrated voice and data networks.
- The economics of low Voice Digitization Rate (VDR) devices.

The emergence of new communications requirements coupled with recent advances in computer and communication technologies have created the conditions under which the sophisticated operational concepts considered in the study became feasible and quantifiable. The major conclusion of this study is that the packet-switching technology is substantially more cost-effective for serving DOD voice or data requirements than the other alternatives examined. This conclusion holds whether voice and data are carried by separate networks or by one integrated network. Potential cost savings range from \$1 million to more than \$70 million per month depending on the volume of data carried and the voice digitization rate employed.

Results and recommendations regarding future DOD communications are provided and the sensitivity of the results are tested with respect to traffic variations, cost trends of switching and transmission, and network performance variables. The significant variables which affect the recommendations are identified and quantified.

The intent of this study is to identify and quantify network technologies which demonstrate long term low operating costs. This is a necessary effort to provide the basis for determining the most cost-effective evolutionary path for DOD communications. It is recognized that transition problems and associated costs may be the most important factors determining the ultimate evolutionary path. However, determining these costs was not an objective of this study. Nevertheless, this study provides a framework and a target technology for detailed transition planning and cost analysis.

II. SYSTEM OPTIONS CONSIDERED

Three broad switching technologies and variations thereof are investigated and compared. The switching technologies are: circuit switching, packet switching, and hybrid (circuit-packet) switching. Each switching technology accommodates either independent voice or data applications or both integrated voice and data requirements. The switching alternatives compared are defined below:

CIRCUIT SWITCHING OPTIONS:

Advanced circuit-switching technology utilizing CCIS (Common Channel Interoffice Signaling) for circuit set up and disconnection is considered.

Traditional Circuit Switching:

An end-to-end circuit is established (set up) for a pair of voice or data users. The end-to-end transmission facilities are dedicated to users for the duration of use. The circuit is disconnected when either party hangs up.

Fast Circuit Switching:

Voice and bulk data applications use the traditional circuit-switching concept. For interactive data users, a circuit is established for every message when ready to be sent and then disconnected after transmission. Specifically, the circuit is not dedicated to the user during his idle "think time" period; however the channel capacity not used during circuit set up and disconnection is taken into account. This concept assumes advanced digital switches enabling the set up of a circuit in 140 msec so that delay requirements for interactive data applications can be satisfied.

Ideal Circuit Switching:

This scenario is almost the same as fast circuit switching except that circuit set up and disconnection are assumed to occur in zero time. Hence no channel capacity is wasted during set up and disconnection. While ideal circuit switching is not physically realizable, it is considered in order to obtain a lower bound on transmission cost for the circuit-switching technology.

HYBRID SWITCHING OPTIONS:

Switching and transmission facilities are dynamically shared between traffic using both circuit-switched and packet-switched modes. Voice is accommodated by the circuit-switched mode, interactive data applications are accommodated by the packet-switched mode, and bulk data applications may use either the circuit-switched or packet-switched modes depending on the operating discipline selected. Two options for sharing of transmission capacity are examined.

Fixed Boundary Frame Management:

The partition of link capacity between circuit-switched and packet-switched traffic is fixed.

Moveable Boundary Frame Management:

While a boundary is assigned between the packet and circuit transmission capacities, packet-switched traffic can dynamically utilize idle channel capacity assigned to the circuit-switched mode.

The hybrid-switching technology was considered in order to provide circuit switching for voice and packet switching for data applications. This technology also provides a potential transition technology to an integrated voice and data packet-switching system. A detailed investigation of the moveable boundary strategy was necessary because the savings in transmission cost that would result by using the moveable boundary strategy could not have been estimated *a priori*.

PACKET-SWITCHING OPTIONS:

Under these options both voice and data are accommodated by the store-and-forward packet-switched concept. However different packet sizes and different transport protocols are used for data and speech. The packet voice protocol options considered are:

Fixed Path Protocol (FPP)

When a voice call originates, a signaling message is propagated to the destination to set up a path for the call. The path set up involves setting appropriate pointers at tandem switching nodes which determine the outgoing link for every input voice packet. No channel capacity is reserved or switch capacity dedicated. Voice packets follow the fixed path. When either party hangs up, the path is released.

Path Independent Protocol (PIP)

In this protocol, no path is set up. Each voice packet is transported to the destination independently of other packets of the same conversation. Packets can use alternate routes as appropriate.

III. ASSUMPTIONS AND DISCUSSION

Assumptions include voice and data traffic volumes to be accommodated, the voice digitization rate of active voice sources, switching and transmission cost components, and network performance requirements.

THE DATA BASE

The traffic data base used is composed of the present DOD voice traffic on the AUTOVON voice system and a scaled DOD data traffic projected for the AUTODIN II data network. Only the projected traffic volume of AUTODIN II is varied whereas the traffic pattern is assumed unchanged. Voice traffic intensity is measured in Erlangs (E) whereas data traffic is measured in Megabits per second (Mbps). The average voice

load in Erlangs is computed by multiplying the average call origination rate by the average holding time per call. An average load in Erlangs is equivalent to the average number of circuits that will be occupied by voice subscribers. The throughput requirements of the voice traffic in bits per second when the analog voice waveform is converted to digital form for transmission depends on the voice digitization rate.

The nominal traffic requirements are 2,700 Erlangs (E) AUTOVON voice traffic, and 36.15 Mbps scaled AUTODIN II data traffic. Data traffic is assumed to be composed of bulk data transfer applications and interactive applications. The nominal volume composition assumes 50% bulk and 50% interactive but is varied over a wide range for sensitivity analysis. In addition to the nominal data traffic of 36.15 Mbps, system costs are obtained for data throughputs of 11.6 Mbps, 86.8 Mbps, and 202.4 Mbps. Moreover, cost and performance for voice load requirements of 675 Erlangs and 1,350 Erlangs, (25% and 50% of the AUTOVON load) are also investigated. The voice digitization rate considered is varied from 2.4 Kbps to 64 Kbps for an active speech source. The combination of variation of traffic and voice digitization rate results in consideration of digital traffic ranging from 3% voice and 97% data to 94% voice and 6% data.

COST MODELS

Transmission:

Cost factors are based on current procurement estimates for tariffed communication lines and hardware. Communication line costs include mileage, termination and modem charges and are calculated for the backbone network communication lines. The current AT&T Digital Data Service (DDS) tariffs are used in the study.

Switching:

Cost factors include purchase price, installation, initial support, operations, maintenance, and amortization. Cost factors not considered are network management costs, the security costs of specially cleared switches, operational personnel, and the cost of encryption devices.

The following components are taken into account in computing processing capacity, memory size, and switching cost. Processing Components include: Operating System Overhead, Circuit-Switching Rate, Data Packet-Switching Rate, Voice Packet-Switching Rate, Total Character Transfer Rate, and Hybrid Switch Complexity (Frame Rate, Circuit and Packet Rates per Frame, Moving Boundary Complexity). Memory Components include: Memory Overhead, Storage for Tables (Circuit and Packet Routing Tables, Calls in Progress Tables), and Storage for Store-and-Forward Data.

The switch cost model corresponds to current costs of computer systems. The cost of switching nodes is a function of processing capacity requirements, storage requirements, and the cost of channel interfaces. Switch complexity is taken into account and expressed in the processing capacity. Typically, for the same throughput requirements, a hybrid switch is the most costly and a circuit switch the least costly switch. Purchase price per switching node ranges from \$1.8 million to \$27 million depending on the voice digitization rate, the switching technology, and the amount of data and voice traffic to be accommodated. Note that because of the small number of switches used in comparison to AUTOVON, each switching node must have substantially higher throughput than the AUTOVON switches. In addition these switches must process 25 times the data traffic projected for the initial AUTODIN II system. The highest switch costs are obtained at voice digitization rate of 64 Kbps (PCM rate). The cost of low bit rate VDR devices is parametrized in the study.

Apart from current switching and transmission costs, the sensitivity of network cost to component hardware and transmission costs is derived using two cost scenarios:

1. Switching Cost - 10% of current
Transmission Cost - current.
2. Switching Cost - current
Transmission Cost - 10% of current.

Conversion Factor: The switch and VDR device costs are given in purchase price and are converted to monthly cost using cost procedures utilized by the Defense Communications Agency (DCA). The conversion factor is based on a 10-year amortization plan; it includes installation charge at 20% base cost, initial support charge at 67% base cost, and a 10-year operation and maintenance cost at 47% base cost. It assumes a redundancy factor of 1.5 for equipment, a capital factor of about

5% per year, based on 10% annual interest over 10 years. Using the above analysis results in a Conversion Factor of 0.0438 from Purchase Price to Monthly Cost.

NETWORK PERFORMANCE

In the circuit and hybrid-switching technologies voice calls are engineered on a blocking basis and data subscribers on a delay basis. Blocking implies that a certain percentage of voice calls will be rejected by the system via a busy tone because of unavailability of facilities. Data subscribers under the circuit-switching technology are assumed to automatically redial every 10 msec when blocked, until an end-to-end circuit is established. The packet switching network is engineered on a delay basis for voice and data subscribers.

All networks are engineered for nominal:

- 1% end-to-end blocking for circuit switched voice
- 200 msec end-to-end packet delay for interactive data users and packet voice.
- 600 msec end-to-end packet delay for bulk data applications.

The percentage of blocked calls for which the networks are engineered is varied from 0.4% to 10%, and the end-to-end packet delay is varied from 200 msec to 1 sec; the corresponding network cost is calculated to determine the effect of performance requirement variations.

NETWORK STRUCTURE

The investigation and comparison of switching technologies is developed for backbone networks with backbone switching nodes at the 8 AUTODIN I switch locations. The backbone voice traffic corresponding to these locations is determined by assigning the current AUTOVON switch traffic requirements to the 8 backbone nodes according to the nearest distance criterion. Network links and their capacities are obtained by automated network design techniques using the minimum cost criterion subject to satisfying network performance requirements. However, a two-connectivity (each node connected to at least two other nodes) requirement is imposed to guarantee network reliability.

The number of backbone nodes is held constant in the present investigations since previous studies conducted by Network Analysis Corporation have shown that the optimum number of backbone nodes for comparable throughput levels ranged from five to twelve, and that the cost differences in this range are insignificant. Moreover, well designed networks with as many as 30 distributed switches have been shown by NAC to lead to networks with communication and hardware costs only a few percent above the minimum. Thus, the number of backbone nodes is not a critical issue from a communications efficiency perspective and this number can be determined based on other criteria such as security and survivability.

Detailed design of the local distribution networks is not addressed in this study. However, preliminary analyses of local distribution network technologies result in the expectation that the relative ranking of switching technologies identified in this report will be preserved. Previous studies conducted by Network Analysis Corporation have shown that the cost of local distribution networks is on the order of 50% of the total system cost. Hence the absolute cost differences between the alternative switching technologies is expected to be twice the costs identified in this report. It is desirable to validate and refine these preliminary estimates at the earliest possible time.

LOCATION OF VOICE DIGITIZATION DEVICES

Investigations are performed under one of the following assumptions:

1. Voice requirements occur in the backbone network in digital form at the bit rate indicated. The location and cost of the digitization process is not considered.
2. Voice is digitized at the origination backbone node.
3. Voice is digitized at subscriber handsets.

The absolute backbone network cost differences between alternative network technologies are independent of the location of the digitization process, and are not affected by the location of the voice digitizers. Under Assumption (2) low bit rate digitizers are provided in the backbone network with the objective of reducing total system cost. This case is applicable for public voice and data systems or for DOD subscribers which do not require end-to-end encryption. An integrated DOD system

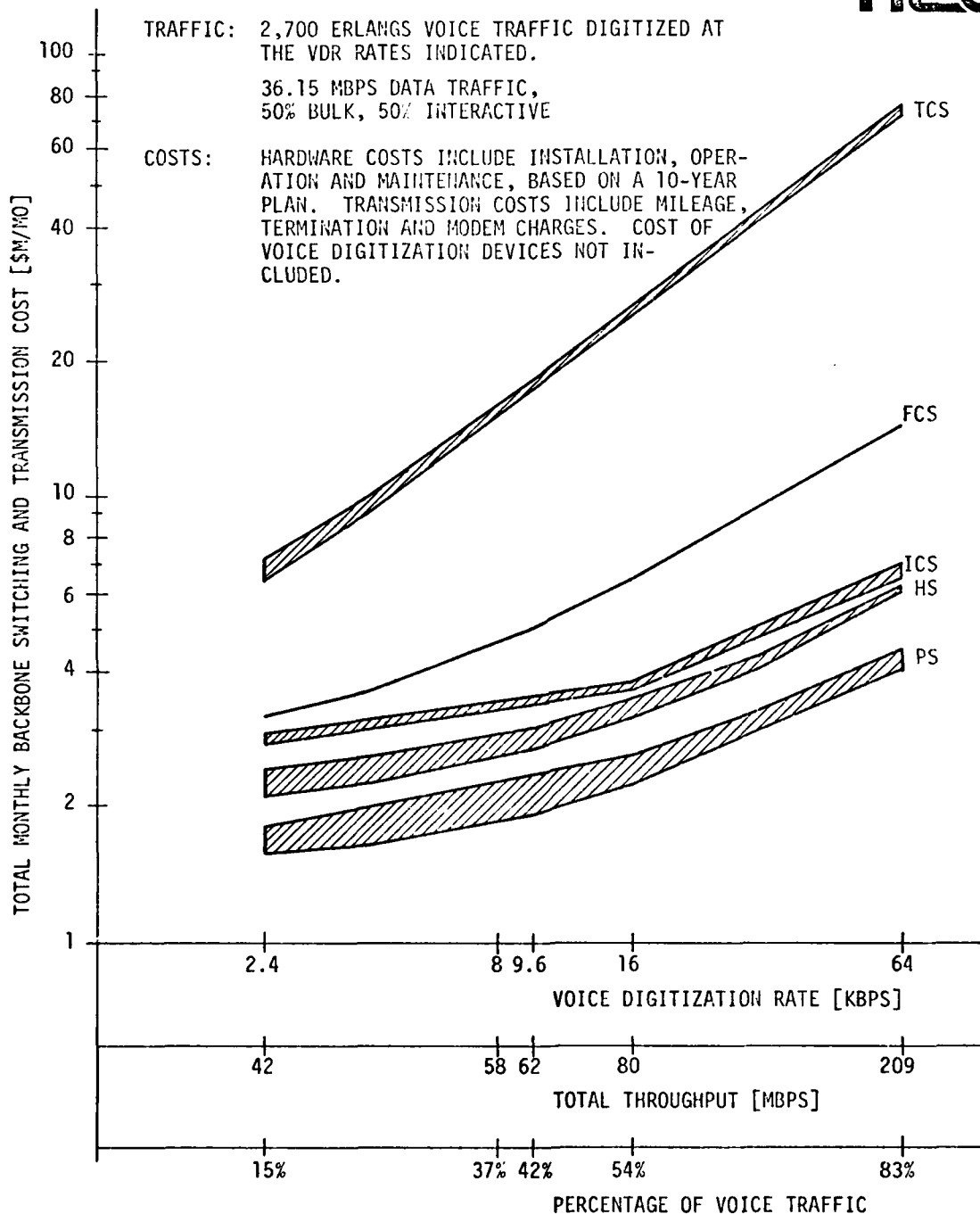
may consist of some subscribers with digitizers at the handset and other subscribers whose voice signals are digitized in the backbone network. Assumption (3) relates to the case where all DOD subscriber handsets include voice digitizers. In this case, while total cost of digitizers would increase because of the larger number of units required, savings would be generated by reducing the cost of local access. Those savings were not investigated but are expected to be greatest under the packet-switching technology because of its inherent multiplexing capability.

IV. CONCLUSIONS

The major conclusions of the investigations are summarized below and illustrated in Figures 1 - 3:

- On the basis of total network cost (lines and switching), the ranking of switching technologies in increasing cost for integrated voice and data is: Packet switching, hybrid (circuit-packet) switching, ideal circuit switching, fast circuit switching, traditional circuit switching (Figure 1).
- The ranking of switching technologies remains virtually unchanged under a variety of traffic, cost, and parameter assumptions, with packet switching providing the lowest cost networks for all cases studied. This conclusion is independent of whether voice and data are carried on separate networks or a single integrated network.
- The network costs of alternatives to the packet-switching technology range from 30% to over 1700% higher than packet switching. Packet switching remains superior to the other technologies even if switching or transmission costs decrease by a factor of 10. Network cost as a function of technology, element cost, and voice digitization rate are shown in Figure 2.
- For any network technology, the vocoder bit rate adopted by DOD is a significant factor affecting the cost of future DOD integrated voice and data networks. Traditional circuit switching can gain the greatest cost savings by using low rate digitizers. However, even with 2.4 Kbps VDR devices, traditional circuit-switching network costs are higher than costs of

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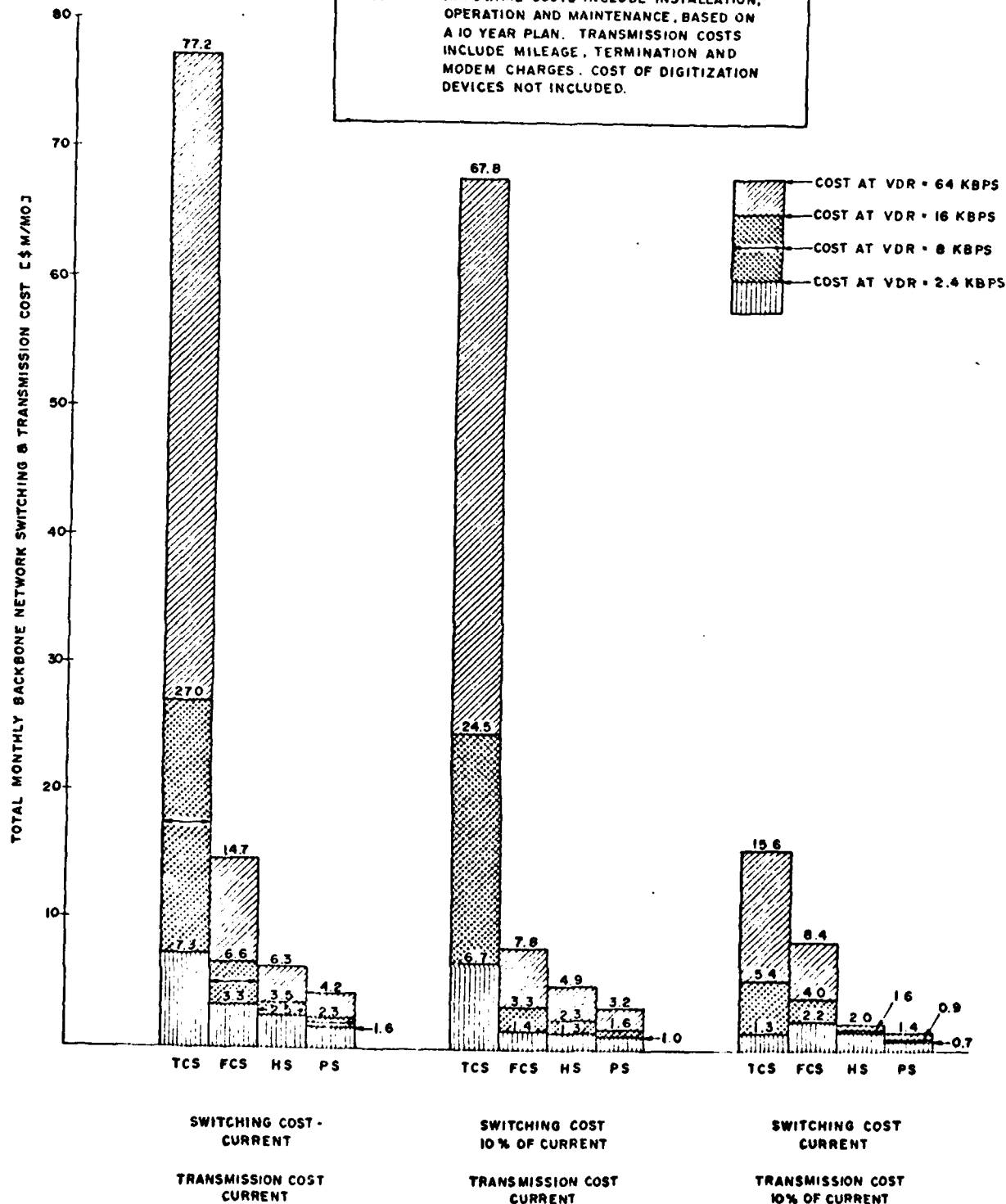
MONTHLY BACKBONE SWITCHING AND TRANSMISSION COST AS A FUNCTION OF VOICE DIGITIZATION RATE (VDR) AND SWITCHING TECHNOLOGY (TCS - TRADITIONAL CIRCUIT SWITCHING; FCS - FAST CIRCUIT SWITCHING; ICS - IDEAL CIRCUIT SWITCHING; HS - HYBRID SWITCHING; PS - PACKET SWITCHING). COST RANGES INDICATE ALTERNATIVE OPERATION SCENARIOS (HS AND PS) OR BLOCKING PROBABILITY RANGE (TCS, ICS).

FIGURE 1

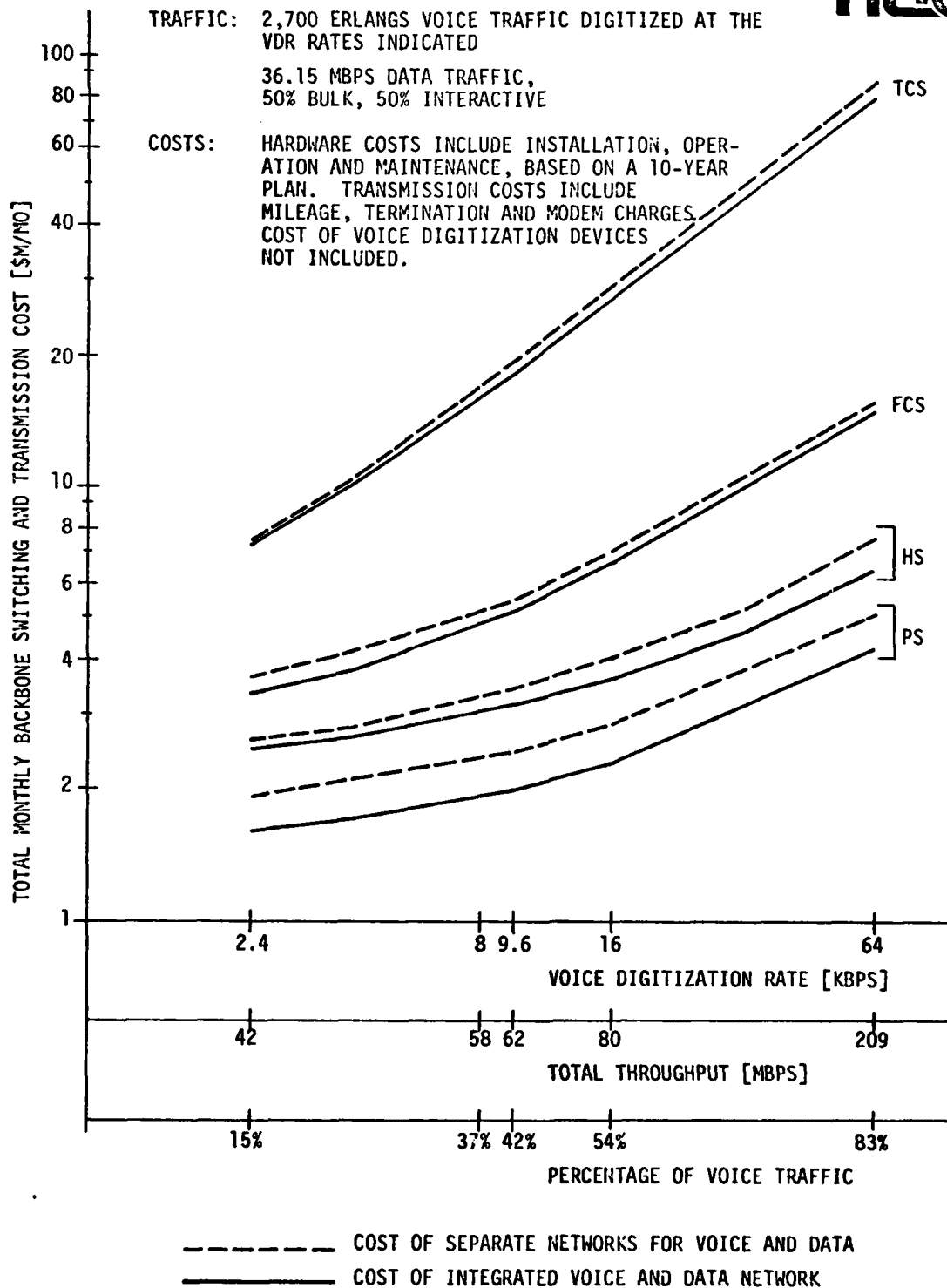
TRAFFIC: 2,700 ERLANGS VOICE TRAFFIC
DIGITIZED AT THE VDR RATES INDICATED.

36.15 MBPS DATA TRAFFIC,
50% BULK, 50% INTERACTIVE.

COSTS: HARDWARE COSTS INCLUDE INSTALLATION,
OPERATION AND MAINTENANCE, BASED ON
A 10 YEAR PLAN. TRANSMISSION COSTS
INCLUDE MILEAGE, TERMINATION AND
MODEM CHARGES. COST OF DIGITIZATION
DEVICES NOT INCLUDED.



MONTHLY BACKBONE SWITCHING AND TRANSMISSION COST AS A FUNCTION OF VOICE DIGITIZATION RATE (VDR), COMPONENT COST, AND SWITCHING TECHNOLOGY (TCS - TRADITIONAL CIRCUIT SWITCHING, FCS - FAST CIRCUIT SWITCHING, HS - HYBRID SWITCHING, PS - PACKET SWITCHING)



INTEGRATED VERSUS SEGREGATED VOICE AND DATA NETWORKS AS A FUNCTION OF VOICE DIGITIZATION RATE (VDR) AND SWITCHING TECHNOLOGY (TCS - TRADITIONAL CIRCUIT SWITCHING; FCS - FAST CIRCUIT SWITCHING; HS - HYBRID SWITCHING; PS - PACKET SWITCHING)

FIGURE 3

packet-switching networks utilizing 64 Kbps digitizers (Figure 1). It is recognized that low bit voice digitization rate DOD systems may encounter speech quality degradation under noisy environments and the lowest rate devices may not be acceptable throughout the DOD. However, the superiority of the packet switching technology was demonstrated over the entire (2.4 Kbps - 64 Kbps) VDR range. Furthermore, both the relative and absolute cost savings achieved by packet-switching increase as the voice digitization rate increases.

- Network cost was found to be insensitive to parameter variations such as: blocking probability (.04 to .1) for which the network is engineered, end-to-end average packet delay (within 200 msec to 600 msec), and priority alternatives. This conclusion holds for each of the alternative network technologies.
- The moving boundary frame management strategy in hybrid switching was demonstrated to be slightly more cost-effective than the fixed boundary frame management strategy. However, the cost difference appeared to be insignificant with an upper bound of 5% within the range of parameters investigated.
- An important factor in hybrid switching is the partition of the traffic between circuit-switched and packet-switched services. With hybrid-switching, bulk data applications should either use a longer packet size or be served by the circuit-switched subnet. Design options which use a mix of long and short packets are viable when high bit rate communication channels are used. Such channels are required for high traffic volumes, and thus do not impose additional cost for the systems studied.
- Security considerations may dictate that voice digitizers are placed at the subscriber handsets rather than at the backbone nodes. This implies that the total cost of the voice digitizers may become an appreciable component of the total system cost. Under this option, the absolute cost savings of the packet-switching technology with respect to any of the alternatives is expected to be at least twice the values obtained because of the ability to achieve substantial savings in the local and regional distribution networks under the packet-switching technology.

- While detailed security issues were not investigated, if link encryption is used to protect the backbone communication channels, packet switching requires less encryptors (and hence lower cost) because the packet-switching networks require fewer links to meet traffic requirements.
- Segregated voice and data networks result in the following cost increases over an integrated voice and data network (for VDR values between 2.4 Kbps and 64 Kbps):

1.2% - 6.4%	under traditional circuit switching
3.3% - 10.2%	under fast circuit switching
4.6% - 13.1%	under hybrid switching
17.1% - 21.7%	under packet switching.

Segregated packet systems for voice and data cost less than integrated systems using either the hybrid or circuit-switching technologies (Figure 3).

The above conclusions are based on economic analysis of network technologies. Other factors, not reflected in the cost comparison, which impact the choice of the network technology are briefly discussed.

Applications:

The packet-switching technology is more suitable for applications involving message dispatching to multidestinatons and conferencing. The advantages would be reflected in the cost but, no such applications were posed in the study. A further advantage of conferencing using packet switching is the ability to sustain conference connectivity in the presence of link outages.

Priority and Precedence Levels:

Provision of priorities in a circuit-switched network environment requires dedication of facilities to high priority customers (overdesign) or the need to preempt low priority calls in progress under high load conditions. In the latter case, preempted subscribers may place additional burden on the system by redialing. Packet switching has no inherent need for preemption. The impact of high load high priority traffic on low priority subscribers is longer packet delays, rather than lack of connectivity.

The packet-switching technology can accomodate different access and transport priorities. For example, subscriber A may have higher access priority (ability to establish and sustain communications) than B, yet lower transport priority (no criticality in delivery delay).

Interoperability:

Packet switching is inherently a more suitable vehicle for communications using various media, technologies, and systems (interoperability). With this technology, interoperability is accomplished via "gateways" which interface different networks. Interoperability is expected to be a significant problem during the evolution of DOD communications to an integrated system, in particular, if reliance on existing facilities is to be maximized. Furthermore, interoperability is expected to be a continuous requirement for communications between subscribers in strategical and tactical systems.

Security:

An integrated DOD communications system is expected to provide message security by end-to-end and/or link encryption. One of the design objectives in providing security is the protection of system performance (availability and responsiveness). It is noted that switching technologies which establish and dedicate end-to-end resources are more vulnerable with link encryption techniques using link synchronization where the receiving crypto derives key synchronization by counting characters in the received data stream. Once the encryption devices lose synchronization (e.g., by short duration jamming) reestablishment may require a relatively long period of time. Naturally, messages using a dedicated circuit will be lost but more significantly, the end-to-end dedicated circuits which utilize the desynchronized link may have to be reestablished.

Risk:

The circuit-switching technology is relatively simple and well established, and thus the adoption of circuit switching minimizes the risk of development and

implementation. Although, the long term lowest cost network technology alternative is packet switching, analog and digital circuit switching are expected to be used during the transition period.

VI. RECOMMENDATIONS

The following recommendations are offered.

- Adopt the packet-switching technology as the prime alternative for future integrated DOD voice and data networks. If the potential cost savings of the packet-switching technology are to be realized, a detailed examination of the transition issues to be encountered in evolving from DOD's current circuit-switched voice network must be performed. The development of this transition plan is of major importance because the compatibility of existing communication technologies is not a solved problem. To the extent that DOD low voice digitization networks are required to interface with higher rate systems (either domestically or abroad), higher near term costs than the costs projected here may be encountered.
- If the detailed costing of a second alternative is desired, the hybrid-switching technology should be pursued.
- Develop a network test bed for the experimental investigation of packet voice communication and integrated voice and data communications. Specific near term problems to be investigated are:
 - Determination of the minimum size of the test bed required to operationally validate the use of packet switching for voice.
 - Network wide and destination switch processing algorithms for smoothing the packet speech stream.
 - Simultaneous operation under several bit rate vocoders.

- Investigation of alternative packet speech transport and control protocols.
- Investigation of cost of local access for voice as a function of voice digitization device rate and location.

• It was demonstrated that regardless of the network technology used, the incorporation of low bit rate vocoders significantly lowers DOD communications cost. Hence, it is recommended that the development of these devices and their incorporation into DOD networks be accelerated.

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